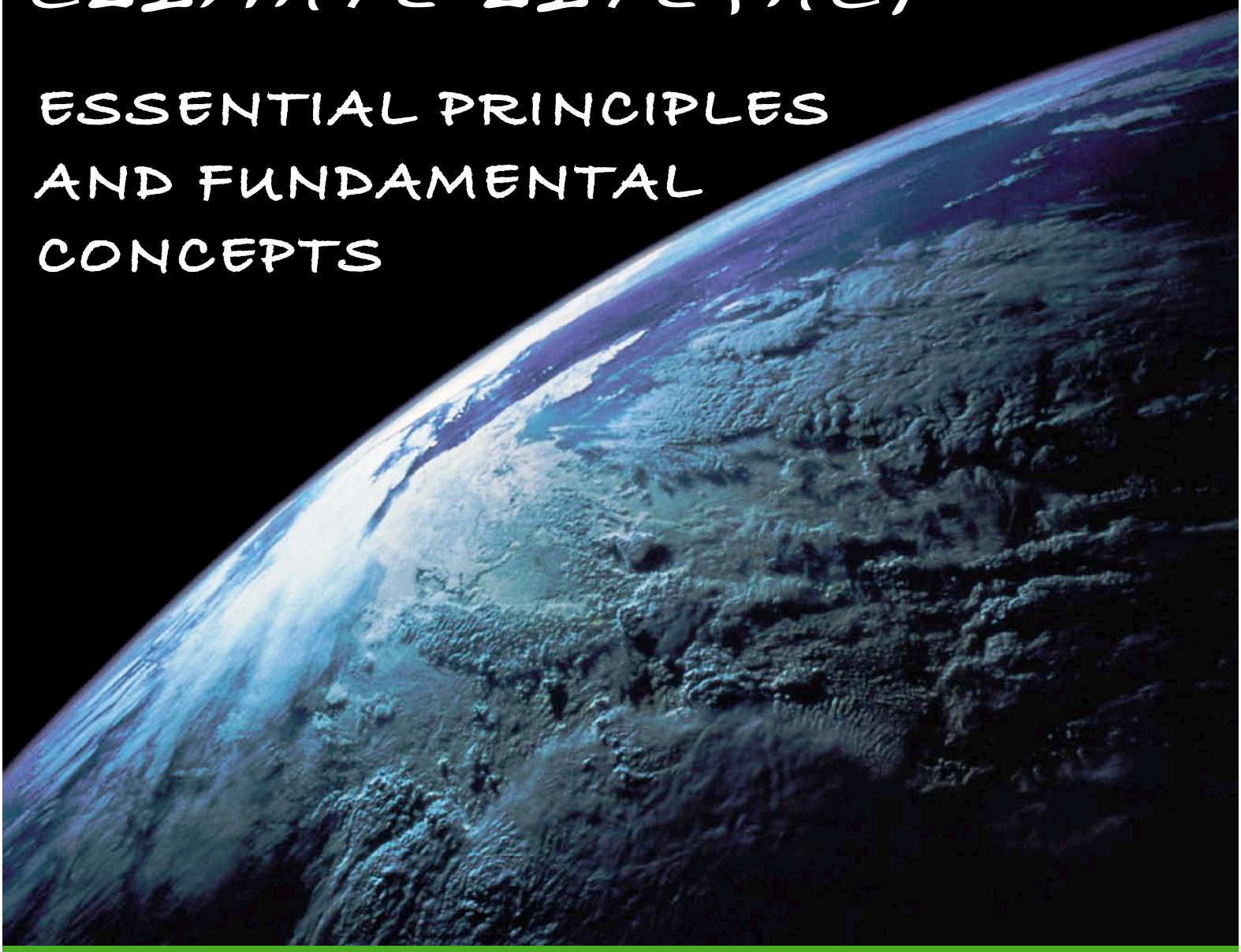
A CLIMATE-ORIENTED APPROACH
TO TEACHING SCIENCE STANDARDS

CLIMATE LITERACY

ESSENTIAL PRINCIPLES AND FUNDAMENTAL CONCEPTS



EACH ESSENTIAL PRINCIPLE IS SUPPORTED BY FUNDAMENTAL CONCEPTS COMPARABLE TO THOSE UNDERLYING THE NATIONAL SCIENCE EDUCATION STANDARDS (NSES) AND AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE (AAAS) BENCHMARKS.

CONSULT THE **OVERVIEW MATRIX** (UNDER DEVELOPMENT) TO INTEGRATE CLIMATE LITERACY INTO YOUR CURRICULUM.

Climate Literacy: Essential Principles and Fundamental Concepts

This Climate-oriented guide to teaching science standards was developed with input from recent workshops and discussions and reflects the current efforts in defining climate literacy. In part, it is modeled after the work conducted by American Association for the Advancement of Science (AAAS) Project 2061, federal science agencies, educators, and other organizations' efforts to identify essential principles and fundamental concepts for Ocean Literacy and related work in other areas of Earth systems science education.

What is Climate Literacy?
You are climate literate if you understand the influence of climate on yourself and society and your influence on climate. A climate literate person:

- understands the essential principles of all aspects of the Earth system governing climate patterns that are presented in this document;
- knows how to gather information about climate and weather, and how to distinguish credible from non-credible scientific sources on the subject;
- understands the influence of climate and weather on human society as well as the influence of human society on climate and weather patterns;
- communicates about climate and climate change in a meaningful way; and
- makes scientifically informed and responsible decisions regarding climate.

Climate changes

Throughout Earth's history, climate has changed. Sometimes change has been slow, over centuries and millennia, influenced by changes in the Earth's orbit or movement of tectonic plates. Sometimes change has been abrupt, caused by sudden events such as volcanic eruptions, collisions with meteors or shifts in ocean currents. Organisms and ecosystems have either adapted to the changes or perished.

Earth's climate has influenced human history in profound ways, playing an integral role in whether societies thrive or fail. And we now know that, conversely, human activities -- such as burning fossil fuels and deforesting large portions of land cover – have a profound influence on Earth's climate.

To protect fragile ecosystems and build sustainable communities that are resilient in the face of natural disasters as well as climate change, a climate literate citizenry is essential. This framework for climate literacy identifies the essential principles and fundamental concepts that individuals need to understand in order to make appropriate decisions about human activities that affect the climate now, and to prepare for adaptations to climate change by future generations.

The 21st century may become known as the Climate Century, yet the majority of citizens do not have a basic understanding of the dynamics of the atmosphere and climate processes. Many educated adults struggle to comprehend such basic relationships as that between Earth's seasonal changes and the tilt of the planet on its axis, or

Key Definitions

"Weather" The atmospheric conditions at any given time or place. Such conditions include temperature, precipitation, humidity, air pressure, cloudiness, and wind speed and direction.

"Climate" The atmospheric conditions (i.e., weather variables) averaged over a long period of time (season, year, or longer) and over a large area (region, continent, or larger).

"Climate Change" Refers to long-term changes in the climate. Climate change can be natural (e.g., ice ages were caused by changes in the distance between the Earth and the sun), or might be caused by changes people have made to the land and atmosphere (e.g., urbanization, pollution).

"Climate System" The five physical components (atmosphere, hydrosphere, cryosphere, lithosphere, and biosphere) that are responsible for the climate and its variations.

between the role atmospheric carbon dioxide in developing tree mass and the effects of its odorless release when trees are burned. Despite recent films, television programs and publications about human impacts on the climate system, many people still inaccurately associate the problem of global warming with the hole in the ozone layer.

Climate is an ideal interdisciplinary theme for education. At a basic level, climate is a function of the movement of energy, water and carbon through time and space, influenced by air, water, land, ice, and living beings. This complex topic can best be understood by beginning with simple concepts and observations of weather and annual cycles. Students can then build increasingly complex inquiries into the many dimensions of climate: physical, chemical, biological, geographical, social, economic, historical and even technological. As students advance in their learning, this education can equip them to understand the interplay of these factors on the climate and to use this understanding wisely in their personal life and in their role as citizens.

Challenges

Teaching weather and climate is a substantial yet rewarding challenge that crosses numerous academic disciplines, The *Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future* National Academies report (http://www.nap.edu/catalog.php?record_id=11463) highlights how the shortage of highly qualified K–12 teachers has forced many of the nation's 15,000 school districts to employ teachers who lack a background in the subject matter that they are asked to teach. Research indicates that some concepts, such as the role of Earth's axial tilt in producing the seasons, and how longer-term orbital fluctuations affect the distribution of solar energy reaching Earth's surface, require a level of cognitive development that make them inappropriate for teaching to younger students. For the youngest students, the forecasts of melting ice caps and the extinction of species can be emotionally overwhelming, producing "eco-phobia" and a sense of paralysis. Despite such concerns, it is nonetheless essential that people of all ages gain an understanding of the issues surrounding climate change and an appreciation of their magnitude and significance, so as to make responsible decisions about human activities that influence Earth's climate.

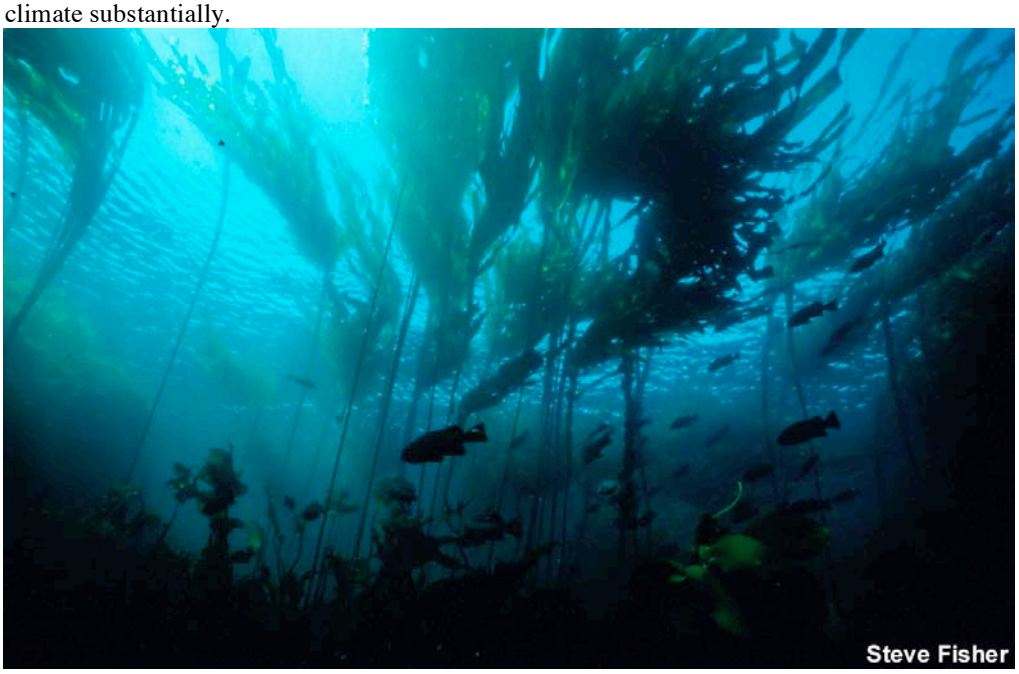
Cover photo source: NASA

LIFE & CLIMATE ARE LINKED

1. ESSENTIAL PRINCIPLE: Life on Earth has been shaped by, depends on, and affects climate.

FUNDAMENTAL CONCEPTS

a. The evolution of organisms can be driven by specific climatological conditions, including but not limited to temperature, humidity, precipitation, and sunlight.
b. Changes in one or more of these climate conditions can produce damaging changes in ecosystems.
c. Changes in environmental conditions can affect the survival of individual organisms as well as entire species.
d. Human societies have developed interconnected food, energy, transportation, and socioeconomic systems that take advantage of existing climate conditions and, thus, are vulnerable to climate changes.
e. Human systems have developed during a relatively stable period in Earth's climate history.
f. Life on Earth, including microbes, plants, and animals such as humans, can sometimes influence climate substantially.



Off the coast of California, Kelp forest provide important structure within the water column, creating food, cover and growing surfaces for many organisms. Image Source: Steve Fisher, NOAA National Marine Sanctuary
http://images.nbii.gov/details.php?id=65315&cat=Vines

THE NATURE OF SCIENCE

2. ESSENTIAL PRINCIPLE: We increase our understanding of the climate system through observation and modeling.

FUNDAMENTAL CONCEPTS

a. Climate science is based on the assumption that Earth's climate system is understandable and, therefore, that many important aspects are predictable.
b. Our understanding of climate differs in important ways from our understanding of weather. Thus, climate scientists' ability to predict climate patterns months, years, or even decades into the future is not constrained by the limitations meteorologists face in forecasting weather on much shorter timescales (days to weeks into the future).[1]
c. We gain understanding of climate and how it has changed over time from observational data from weather stations, buoys, satellites, radars, ice and ocean sediment cores, tree rings, cave deposits, native knowledge, and other sources.
d. Observations, experiments, and theory used to construct and refine computer models and develop scientific explanations lead to better understanding of the climate system's behavior and more reliable projections of future climate changes.
e. Fundamental characteristics of the climate system have been researched and are understood well enough to make reasonably accurate predictions about the climate system and, therefore, to support decision making, even though research continues into many aspects of climate change.

Mauna Loa Observatory at sunset, 2007. Image Source: Forrest M. Mims III,

(1. Based on Climate Change: An Information Statement of the American Meteorological Society [Adopted by AMS Council on 1 February 2007] Bull. Amer. Met. Soc., 88)

SUN DRIVES EARTH SYSTEM

3. ESSENTIAL PRINCIPLE: The Sun is the primary source of energy for the climate system.

FUNDAMENTAL CONCEPTS

a. Solar energy heats Earth's surface and thus the atmosphere, causing movements of air masses and introducing water in the global water cycle.
b. Daily variations in solar energy over Earth, caused by the planet's spherical shape, influence many weather and climate processes.
c. The tilt of Earth on its axis causes solar energy to fall more directly on different parts of Earth during different times of the year, resulting in seasonal changes.
d. Gradual changes in Earth's orbit around the Sun over tens of thousands of years alter the spatial distribution and intensity of solar energy received on Earth, causing long-term warming and cooling trends, such as ice ages and the warm periods in between them.
e. Gases in the atmosphere, such as carbon dioxide and water vapor, temporarily trap infrared radiation from the warmed surface of Earth, creating the "Greenhouse Effect," which allows liquid water and other life-supporting processes to exist on much of Earth's surface.
f. Sunlight is the ultimate source of most of the energy used by humans. The energy in fossil fuels such as oil, natural gas and coal comes from energy captured long ago from the sun.
g. Earth's climate is remarkably sensitive to changes in the planet's energy balance.[2]

Sunlight is the ultimate source of the energy that powers Earth's climate system as well as most of the energy humans use. Image Source: Alberta Environment, http://environment.gov.ab.ca/)

(2. Hansen, J., Mki. Sato, P. Kharecha, G. Russell, D.W. Lea, and M. Siddall, 2007: Climate change and trace gases. Phil. Trans. Royal. Soc. A, 365, 1925-1954, doi:10.1098/rsta.2007.2052.)

COMPLEX INTERACTIONS

4. ESSENTIAL PRINCIPLE: Earth's weather and climate systems are the result of complex interactions.

FUNDAMENTAL CONCEPTS

a. Energy differences within and between the land, ocean, ice cover, and atmosphere result in energy flows that drive weather and climate variations.
b. Earth's atmosphere, oceans, land, and ice are dynamic, but change at different rates. Significant changes in any of these are likely to influence all other components of the climate system in complex ways.
c. Water cycling on Earth is fundamental to weather and climate.
d. The carbon cycle influences climate in a variety of ways, including seasonal interactions between the atmosphere, biosphere, and hydrosphere, and the long term formation and destruction of fossil fuels. Carbon dioxide, an important greenhouse gas, is removed from the atmosphere in the ocean through biologic and geologic processes.
e. Changes in the oceans impact the atmosphere and climate patterns around the globe. In turn, changes in the atmosphere impact the ocean temperatures and currents.
f. Circulation in and evaporation of water from the oceans regulate the temperature of Earth. Changes in deep ocean circulation in the past have produced large, abrupt changes in climate.
g. Relatively small increases in amounts of greenhouse gases—such as carbon dioxide, methane, nitrous oxides and some refrigerants—can magnify the greenhouse effect.
h. Interactions between components of the Earth's climate system result in changes to the system and produce emergent phenomena unique to the system. Human beings are an integral part of Earth's climate system. Human activities such as fossil fuel burning or deforestation can affect climate and alter the equilibrium of the climate system.

At sunset over the Pacific Ocean, anvil tops of thunderclouds cast long shadows. Image Source: ISS007-E-10807 (July 21, 2003, 35 mm lens). http://eol.jsc.nasa.gov/sseop/images/EO/highres/ISS007/ISS007-E-10807.JPG

NATURAL VARIABILITY & CHANGE

5. ESSENTIAL PRINCIPLE: Earth's weather and climate vary over time and space.

FUNDAMENTAL CONCEPTS

a. Weather is understood as the atmospheric conditions at any given time or place. Such conditions include temperature, precipitation, humidity, air pressure, cloudiness, and wind speed and direction.
b. Climate is understood as the atmospheric conditions (i.e., weather variables) averaged over a long period of time (season, year, or longer) and over a large area (region, continent, or larger).
c. Weather and climate variations, such as the seasons or El Niños, can be described by their duration, magnitude or frequency. These variations range from a fraction of a second to many years.
d. The temperature of a specific place on Earth's surface tends to rise and fall in a somewhat predictable pattern every day and over the course of a year.
e. Differences in the intensity of sunlight warm Earth's surface and produce daily, seasonal and long-term variations in temperature.
f. Earth's climate has changed in the past, is currently changing, and is expected to change in the future.
g. The consensus of scientific opinion is that the natural processes driving Earth's long-term climate changes cannot entirely explain the rapid changes observed in recent decades, nor do they solely predict those projected for coming decades.

Greenland Icebergs. Image Source: Ryan Vachon CIRES Outreach

HUMAN ACTIVITIES AND CHANGE

6. ESSENTIAL PRINCIPLE: Recent climate change is very likely due to human activities.

FUNDAMENTAL CONCEPTS

a. Human beings are an integral component of Earth's climate system.
b. Human activities have affected the land, oceans and atmosphere and have altered local, regional and global climate. These activities include burning fossil fuels, releasing chemicals into the atmosphere, reducing the amount of forest cover, and rapidly expanding farming, development and industrial activity.
c. Some changes resulting from human activities have decreased the capacity of the environment to support various species.
d. The increased burning of fossil fuels since the start of the industrial revolution has increased the amount of greenhouse gases in the atmosphere. Because CO2 remains in the atmosphere for many years (hundreds to thousands of years) before being removed by natural processes, this has contributed to Earth's warming.
e. The preponderance of scientific evidence indicates that the observed increase in global average temperatures since the latter part of the-20th century is very likely due to documented increases in human-induced greenhouse gas concentrations, primarily from the burning of fossil fuels.[3]

Coal delivered by train to generate electricity. Image Source: Indiana Office of Energy & Defense Development
http://www.in.gov/energy/images/Coal%20Train.jpg

(3. Based on Climate Change 2007: The Physical Science Basis: Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), http://www.ipcc.ch/)

MAKING DECISIONS

7. ESSENTIAL PRINCIPLE: Earth's climate system is influenced by complex human decisions involving economic costs and social values.

FUNDAMENTAL CONCEPTS

a. Decisions about human activities that affect climate and climate change should involve weighing scientific evidence against uncertainties about future economic growth, energy use, ecosystem integrity, costs and opportunities, moral values, and cultural norms.
b. Identification and understanding of facts and assumptions about climate change are essential to informed decision making to solve related problems.
c. Climate information can be used to reduce the vulnerability/enhance the resilience of human communities and ecosystems; the importance of continuing to improve understanding of climate system is crucial.
d. Industrialization has the potential to improve the quality of life in the short-term but also creates long-term challenges, including increased energy demand and the resultant adverse impacts on ecosystems and the climate system.
e. The atmosphere covers the entire surface of Earth; thus, activities that effect climate (e.g., energy use leading to greenhouse gas release into the atmosphere) in one region affect human beings and other species worldwide.
f. Decisions of one generation both provide opportunities and limit the range of possibilities open to the next generation.
g. Decisions about energy use and adapting to the effects associated with climate change are made at all levels, from the individual to the global.
h. Individuals as well as community, government, business and industry leaders can contribute to climate mitigation and adaptation.
i. Slowing or reversing human impact on climate change trends might be accomplished by combining short-term strategies -- such as conservation, more efficient use of resources, and the switch from carbon-intensive energy to renewable sources -- with long-term investments in technology research and implementation, and by adopting sustainable development strategies, such as building climate-resilient communities.

Agricultural engineers inspect a dry stream channel below a 15-foot flume. Several ARS locations use instrumented watersheds to gather a variety of information. Image Source: Scott Bauer, USDA Agricultural Research Service. http://www.ars.usda.gov/main

Developing the Guide

This guide is the product of a three-day workshop, Climate & Weather Literacy: Using the AAAS Project 2061 Science Literacy Research to Develop Weather and Climate Literacy Framework, in April 2007. The National Oceanic and Atmospheric Administration (NOAA) sponsored this workshop along with the American Association for the Advancement of Science (AAAS). Organizers included NOAA, NASA Goddard Space Flight Center, and the US Climate Change Science Program's Communications Interagency Working Group; the Department of Commerce and the NOAA Office of Education hosted it. The event was planned and coordinated by Ted Willard, AAAS Project 2061; Frank Niepold, NOAA Climate Program Office; Christos Michalopoulos, NOAA Office of Education; and Jon Lilley, NOAA Office of Education. Principal authors of the guide were Frank Niepold, NOAA Climate Program Office, and Mark S. McCaffrey, Cooperative Institute for Research in Environmental Sciences (CIRES)/University of Colorado-Boulder.

NOAA, AAAS Project 2061, NASA, CIRES, American Meteorological Society, and various members of both the science and education communities worked to define climate literacy in the United States. Supported through a NOAA Education Grant, the workshop brought together over twenty individuals representing numerous NOAA offices, other federal science agencies, formal and informal educators, non-governmental organizations, and other vested institutions involved in climate research, education and outreach to work together towards the goal of creating of a framework for climate and weather literacy, building on the research and the science and technology education benchmarks developed by the American Association for the Advancement of Science (AAAS) Project 2061.

The workshop developed the initial framework through an iterative process rooted in education and social research on weather and climate related topics. The development of a robust conceptual framework is an initial step to engage broad community involvement, to address misconceptions about weather and climate, and to establish a unifying structure for developing a climate-literate public. The workshop focused on natural as well as human-induced climate processes and sought to identify the essential concepts that a climate-literate citizen should know. A core group continues to pursue this project. Broader participation by other agencies, non-governmental organizations, and individuals was sought through extensive review and comment periods. Discussion at the National Science Foundation (NSF) / NOAA sponsored Atmospheric Sciences and Climate Literacy workshop, (http://www.eo.ucar.edu/ascl/), contributed substantially to the refinement of this framework.

All draft and final reports will be posted at NOAA's Climate Program Office's Education site, http://www.climate.noaa.gov/education/.

Further information

For future revisions and changes to this document or to see documentation of the process used to develop this brochure, please visit **http://www.climate.noaa.gov/education/.** In addition, further information relating to climate literacy and climate resources can be found at: earthobservatory.nasa.gov/ www.epa.gov/climatechange/• www.dlese.org/• www.education.noaa.gov

The following people also made significant contributions to the development and preliminary review of this guide:

Alan Gould, *University of California Lawrence Hall of Science*
Ann Benbow, *American Geological Institute*
Barbara Herrli, *NOAA/ Earth System Research Laboratory*
Barry Reichenbaugh, *NOAA Oceanic and Atmospheric Research*
Bruce Moravchik, *NOAA National Ocean Service*
Catherine Gautier, *UCSB Santa Barbara*
Chris Donovan, *Albert Einstein Distinguished Educator Fellow*
Christopher Riegle, *WGBH Educational Productions*
Cindy Renkas, *NOAA Ocean Exploration*
Cynthia Hamen, The College Board
Dan Barstow, *TERC*
Dan Fernadez, *Johns Hopkins University*
David Herring, *NASA Goddard Space Flight Center*
David Kirschtel, *Consortium of Universities for the Advancement of Hydrologic Science (CUAHSI)*
Dian J. Seidel, *NOAA Air Resources Laboratory*
Diana L. Perfect, *NOAA/National Weather Service*
Diane Stanitski, *GEOCATION, LLC (formally with Shippensburg University)*
Eileen Shea, *NOAA/National Climatic Data Center (NCDC)*
Fiona Horsfall, *NOAA/ National Weather Service*
Frank Niepold, *NOAA Climate Program Office*
Glenn Dolphin, *Union Endicott High School, New York*
Heather Elmer, *Old Woman Creek National Estuarine Research Reserve, Ohio DNR Division of Wildlife*
James L. Elder, *The Campaign for Environmental Literacy*
Jean McAvoy, *New York State Department of Environmental Conservation, Hudson River Research Reserve*
Jennifer Buchanan, *Grand Bay National Estuarine Research Reserve*
Jeremy Wang, *The College Board*
John Leck, *NASA Goddard Space Flight Center*
Joseph M. Moran, *American Meteorological Society*
Joseph Shewmaker, *Albert Einstein Distinguished Educator Fellow*
Josh Foster, *NOAA Climate Program Office*
Judy A. Reeves, *Albert Einstein Distinguished Educator Fellow*
Julie Thomas McNamee, *National Park Service*
Karen M. Scott, *U.S. EPA, Office of Air and Radiation/Office of Atmospheric Programs*
Karin Jakubowski, *Clean Air-Cool Planet*
Kate Thompson, *National Marine Sanctuary Program*
Kathryn Parker, *U.S. EPA, Office of Air and Radiation/Office of Atmospheric Programs*
Keith Dixon, *NOAA/Geophysical Fluid Dynamics Laboratory (GFDL)*
Kim Benson, *NOAA Office of Education*
Lesley-Ann L. Dupigny-Giroux, *University of Vermont Associate Professor & Vermont State Climatologist*
Lisa Auermuller, *Jacques Cousteau National Estuarine Research Reserve*
Lynn Nakagawa, *NOAA/National Climatic Data Center (NCDC)*
Maggie Kerchner, *NOAA Air Resources Laboratory*
Margaret McCalla, *Office of the Federal Coordinator for Meteorology*
Marina Timofeyeva, NOAA/ National Weather Service
Mark McCaffrey, *Cooperative Institute for Research in Environmental Sciences (CIRES)*
Marlene Kaplan, *NOAA Office of Education*
Mary L. Batteen, *Naval Postgraduate School*

Miriam Lund, *U.S. Department of Education*
Ned Gardiner, *American Museum of Natural History*
Pat Harcourt, Waquoit Bay *National Estuarine Research Reserve*
Patsy Cicala, *Indian River High School, Sussex County, Delaware*
Peg Steffen, *NOAA National Ocean Service*
Peter Schultz, *U.S. Climate Change Science Program Office*
Richard W. Dixon, *Texas State University*
Robert Cifelli, *Colorado State University*
Ron Gird, *NOAA National Weather Service*
Rosalyn F. Kilcollins, Apalachicola National Estuarine Research Reserve
Sadredin Moosavi, *Tulane University*
Sarah Wise, *Visiting Fellow with Cooperative Institute for Research in Environmental Sciences (CIRES)*
Saundra Upchurch, *South Carolina Department of Natural Resources*
Steve Ackerman, *Cooperative Institute for Meteorological Satellite Studies (CIMSS)*
Susan Buhr, *Cooperative Institute for Research in Environmental Sciences (CIRES)*
Susan Joy Hassol, *Climate Communication*
Tamara Shapiro Ledley, *TERC*
Ted Willard, *AAAS Project 2061*
Tim Eichler, *Saint Louis University*
Tom Bowman, *Bowman Design Group*
Wayne Faas, *NOAA/National Climatic Data Center (NCDC)*

More to come (these organizations will be contacted to join the group listed above); UCAR, NEEF, NAAEE, U.S. Forest Service, ASTC, CUAHSI, Weather Channel, National Geographic Society and others.